

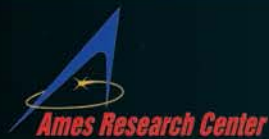
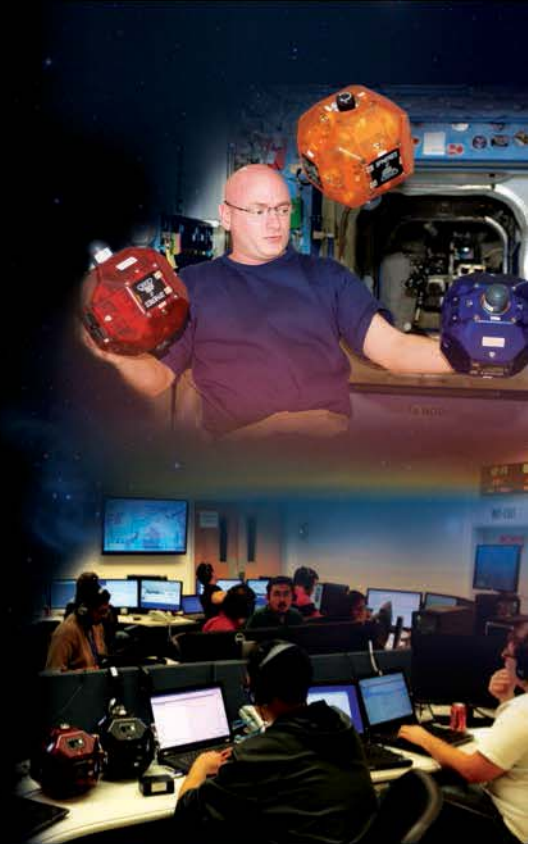
SPHERES

Synchronized, Position, Hold, Engage, Reorient,
Experimental Satellites



SPHERES National Lab Facility

Jose Benavides
NASA Ames Research Center
July 16, 2014





Synchronized Position Hold Engage Reorient Experimental Satellites - SPHERES

- A Facility of the ISS National Laboratory with three IVA nano-satellites designed and delivered by MIT to research estimation, control, and autonomy algorithms
- Installed on ISS in 2006
- Managed by ARC since Fall 2010
- By working aboard ISS under crew supervision, it provides a risk tolerant Testbed Environment for Distributed Satellite & Free-flying Control Algorithms
 - Formation flight,
 - Docking,
 - Close proximity operations
- If anything goes wrong, reset and try again!
- The satellites can be reused
 - ✓ Replenishable consumables
 - ✓ Multiple test sessions assigned per year



Scott Kelly working with SPHERES in the Kibo lab

SPHERES ISS National Lab Facility

- Program Executive: Jason Crusan (HQ)
- Program Manager: Andres Martinez (ARC / R)
- Chief Engineer: Jose Benavides (ARC / TI)
- Operations Lead: Aric Katterhagen (ARC / PX)

If you can't bring the space environment to the laboratory, take the laboratory to space!



SPHERES Platform Capabilities

Sensors

- Accelerometers, Gyroscopes, Ultrasonic ranging
- Smartphone Camera

Actuator

- CO₂ Propulsion, 0.2N of force possible

C&DH

- 115kbps downlink to laptop
- Real-time interface to laptop Matlab runtime
- 400kbps real-time downlink to Mission Operations Center

Expansion Port

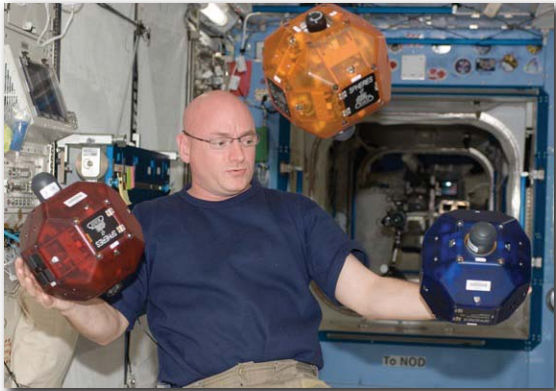
- Provides an interface for integration with additional technologies
- Well documented ICD
- Currently used by several Payloads



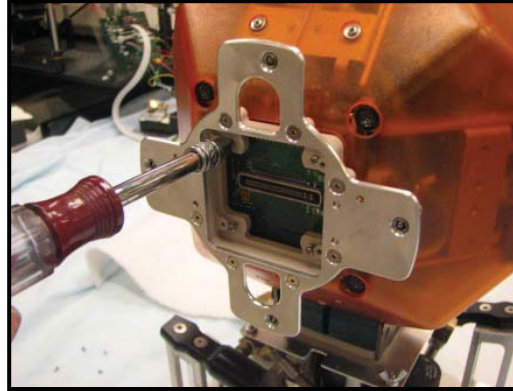
Diameter	8.3 in (0.2 m)
Mass	7.8 lb (3.5 kg)
Thrust (single thruster)	<1 oz (0.2 N)
CO ₂ Capacity	6 oz (170g)



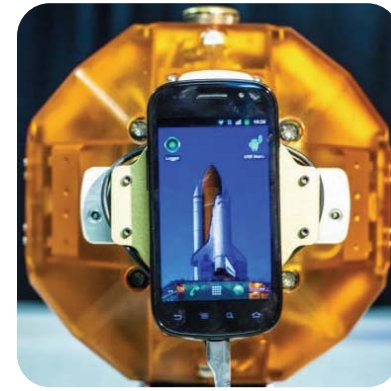
SPHERES Nat Lab Facility



3 SPHERES



Expansion Port Enabled



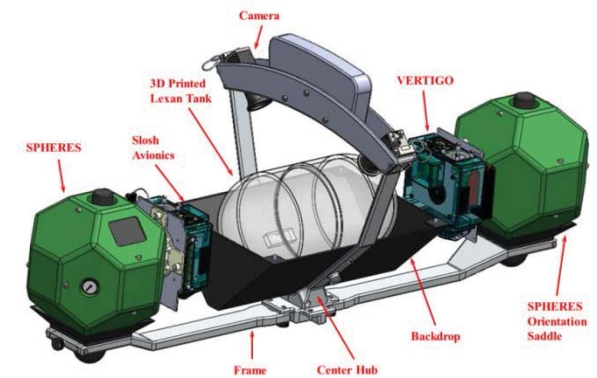
Smartphone



Vision Based Navigation



Electro-magnetic Actuation (RINGS)



Fluid SLOSH



SPHERES Facility Labs



Flight Lab



International Space Station



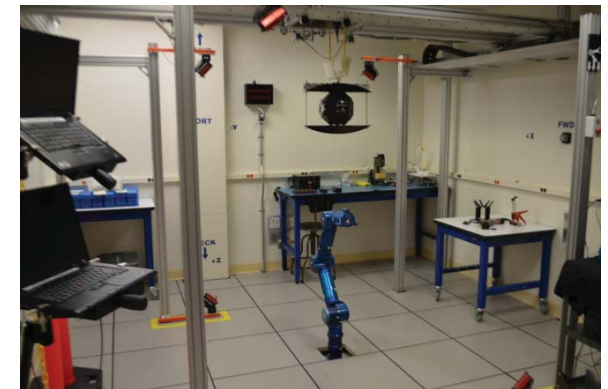
**Engineering Evaluation Lab
(EEL)**



Granite Lab



Mission Operations Center

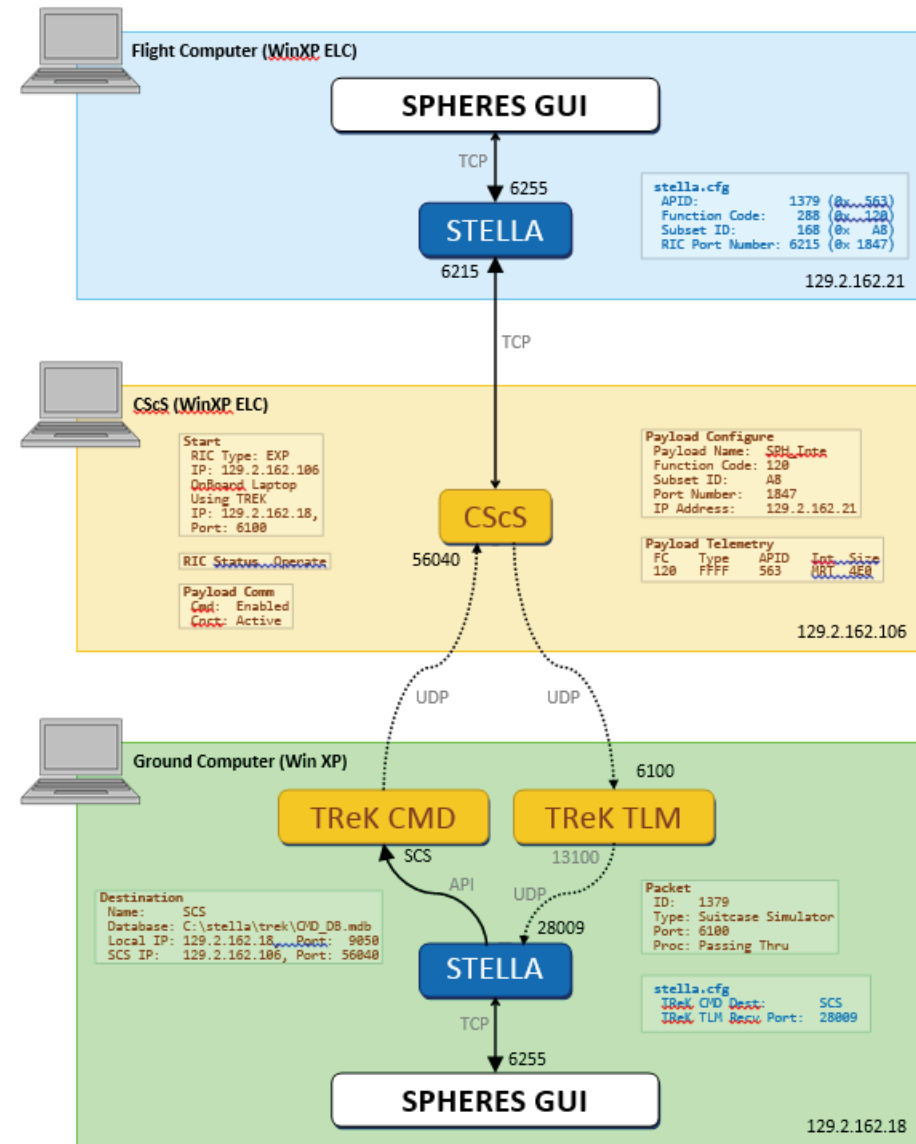


**Micro Gravity Test Facility (MGTF) Lab:
Cradle/Gimbal and Robotic ARM**



MGTF Lab Configured for SPHERES GUI C&DH

- ❑ Emulate space-to-ground end-to-end communication
- ❑ Collect real-time telemetry
- ❑ Send commands
- ❑ Matlab integration





Guest Scientist Program (GSP)

Technical Aspects

1. Download GSP from Sourceforge, including simulator
2. Dev and Test your software on the simulator
3. Test in Ames SPHERES Lab
4. Deliver Software and planning products to SPHERES Operations
5. Conduct test session aboard ISS

Operational Planning Aspects

1. Deliver proposed investigation – one pager
2. SPHERES initiates request to schedule ISS Test Session
3. Generate all planning items required by ISS (e.g. Test Plan,)



SPHERES Simulator Capabilities

Simulator Features

1. **ISS-validated dynamics model**
2. **Matlab/Simulink & C programming environment**
3. **Full embedded architecture fidelity**
 - a) Same C-code developed for Simulator can be re-compiled for SPHERES hardware un-modified
4. **Integration with Simulink 3D Animation toolbox**
5. **Cross-platform compatibility (Windows/Mac OS X)**
6. **Publicly Available :**
 - a) <http://sourceforge.net/projects/issospheres/>



Research & Benefits of SPHERES

- Demonstrated key close-proximity formation flight, rendezvous and docking maneuvers, fault diagnosis and recovery
- Supported human telerobotic operation and control investigations
- Conducted experimental evaluation of algorithms and sensing for autonomous docking, Satellite servicing, Re-supply, Upgrade of space systems
- **Crew-based teleoperation and time-delayed ground control experiments for future crew-assistant robots.**
- Evaluation of COTS technologies such as smartphones for rapid prototyping and deployment in space environments.
- Lessons learned on ISS have significant impact on ground robotics, mapping, localization, and sensing in 3D.
- Developed a platform to demonstrate and validate metrology, control, autonomy, and artificial intelligence algorithms for distributed satellite systems (DSS)
- **Evaluation of Autonomous Inspection operations, damage inspection & characterization**

Over 80 Test Sessions (400+ hrs. of Facility Console activities involving crew), 62 Crew training sessions (Over 100 hrs.).

One of the most used and popular ISS National Lab Facilities



Smartphone Overview

Smartphone

- Converts SPHERES from satellite test-bed to free-flying robot

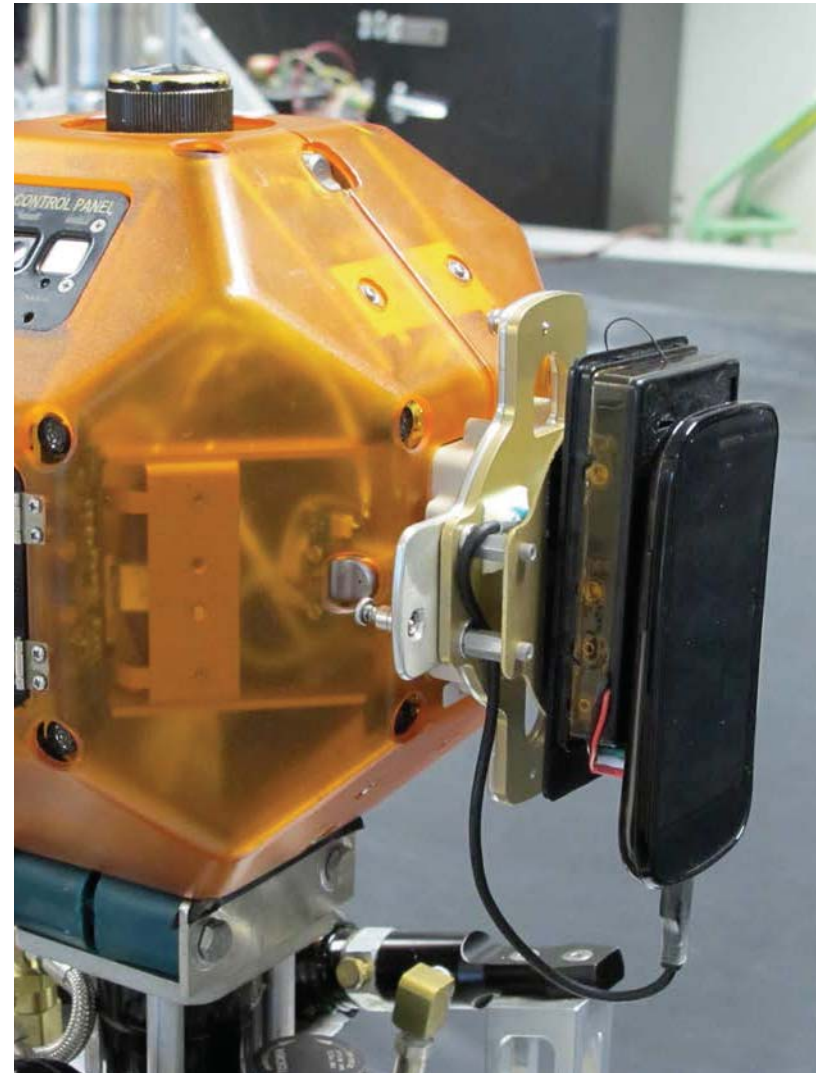
Demonstrate use cases

- Environmental surveys
- Mobile camera inspections

Technology development & risk reduction

- Ground/crew control & communication paths
- Control modes (supervisory vs. manual)
- User interfaces
- Wi-Fi localization
- Vision based navigation

Team Lead: Chris Provencher

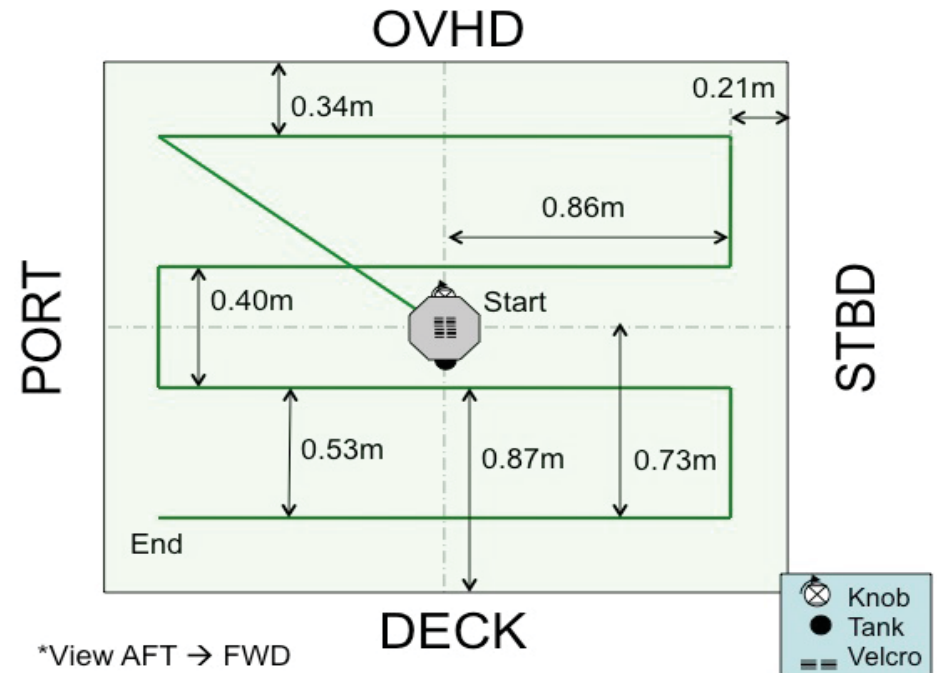


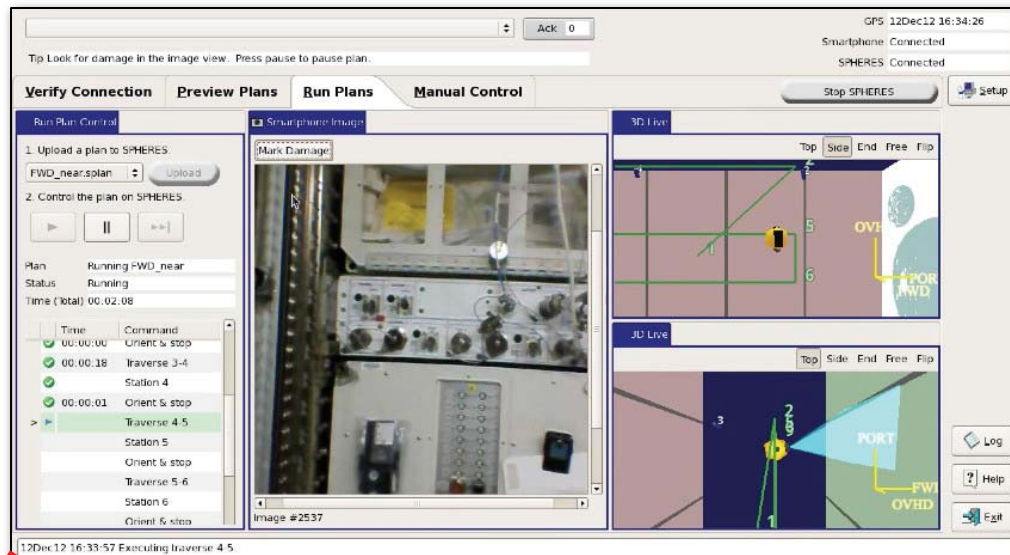


Ground Control Test (Dec 12, 2012)

Space Station Free-Flying IVA Survey

- Demonstrate video survey within ISS (Kibo Laboratory module)
- Smart SPHERES remotely operated by ISS Mission Control (Houston)
- **Manual control** (discrete commanding) and **supervisory control** (command sequences)





Robot operator in
"PLUTO" Multi-Purpose Support Room

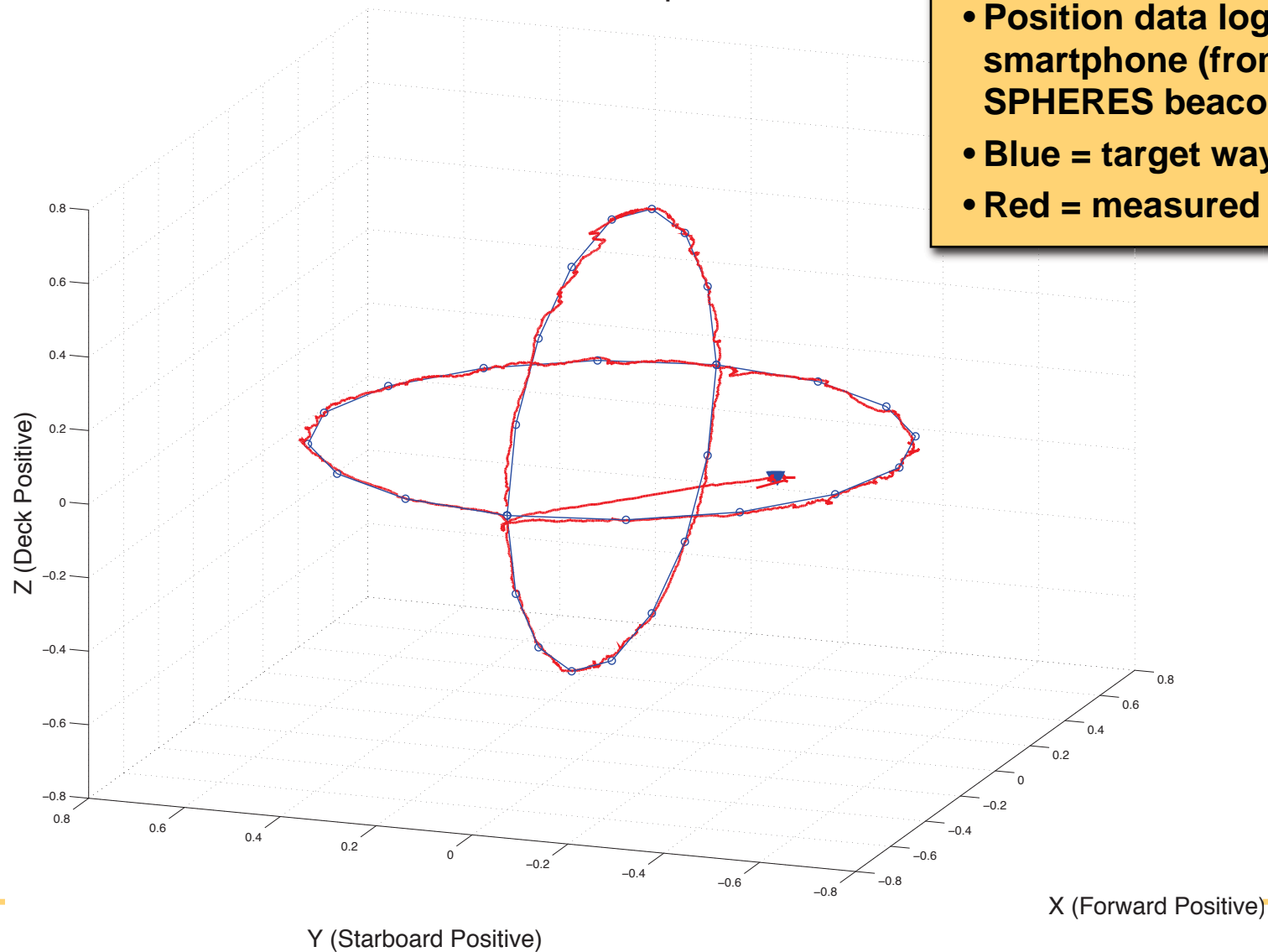






“Plus Orbits” Translation

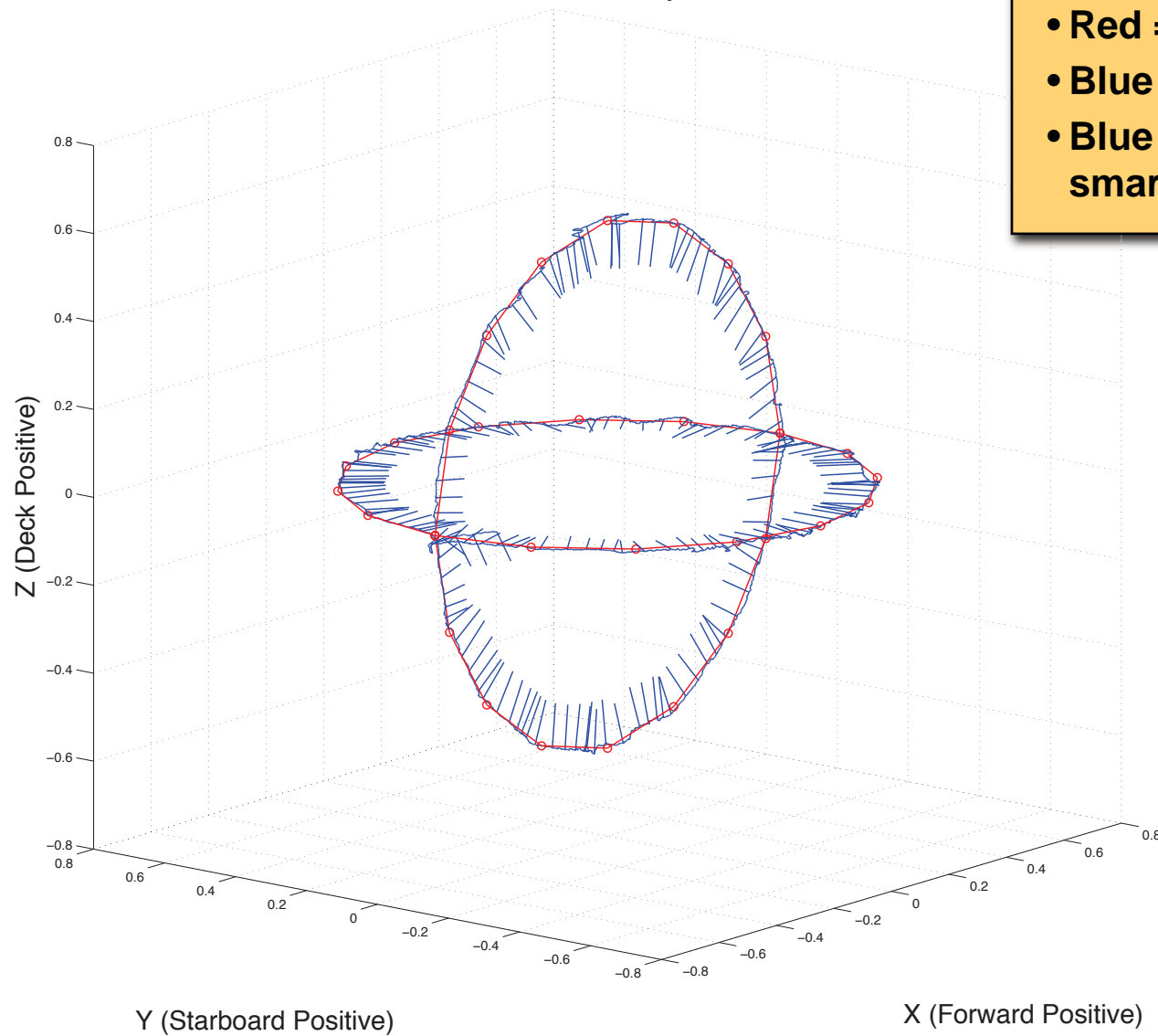
Plus Orbits, Smartphone Data





Plus Orbits Orientation

Plus Orbits, Smartphone Data



- Red = target waypoints
- Blue = measured path
- Blue lines = orientation of smartphone camera



Inspection Coverage

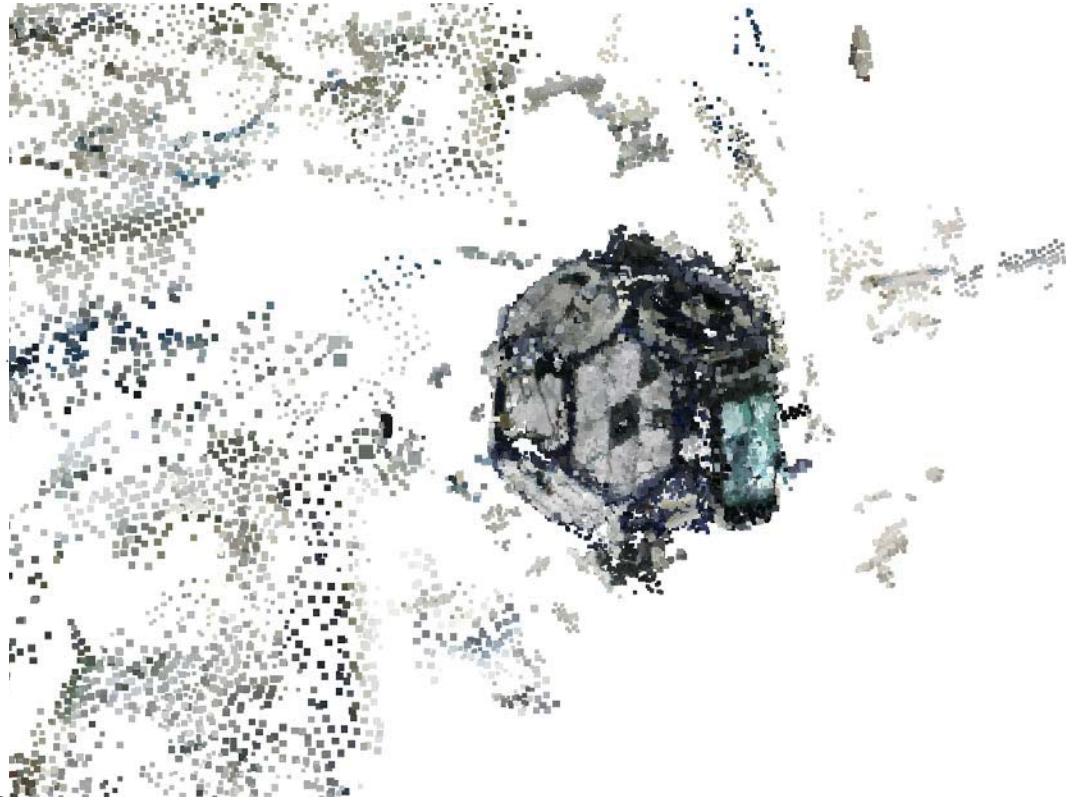
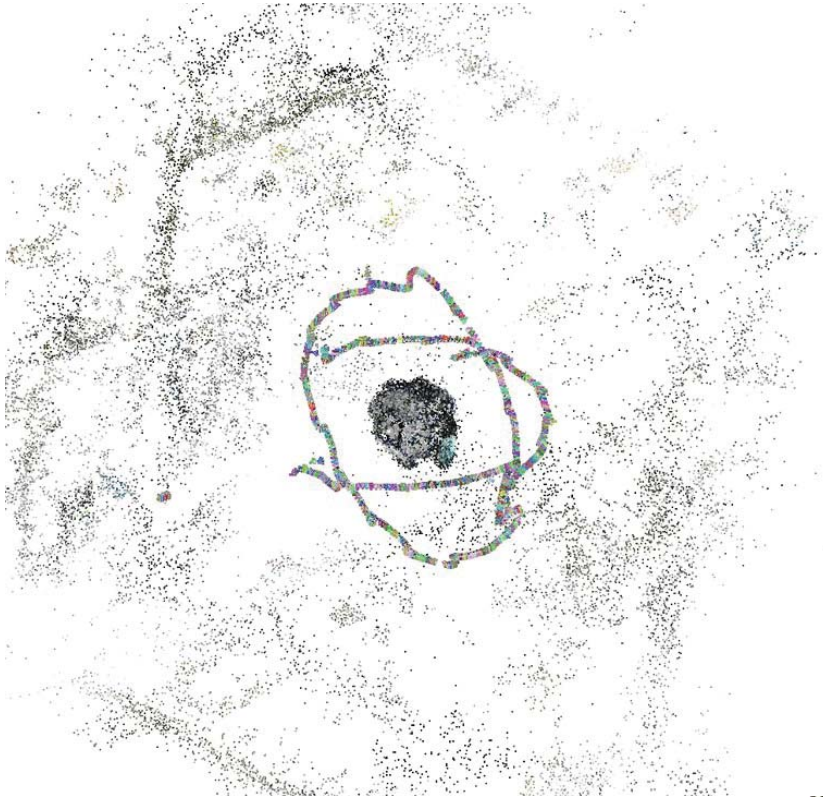
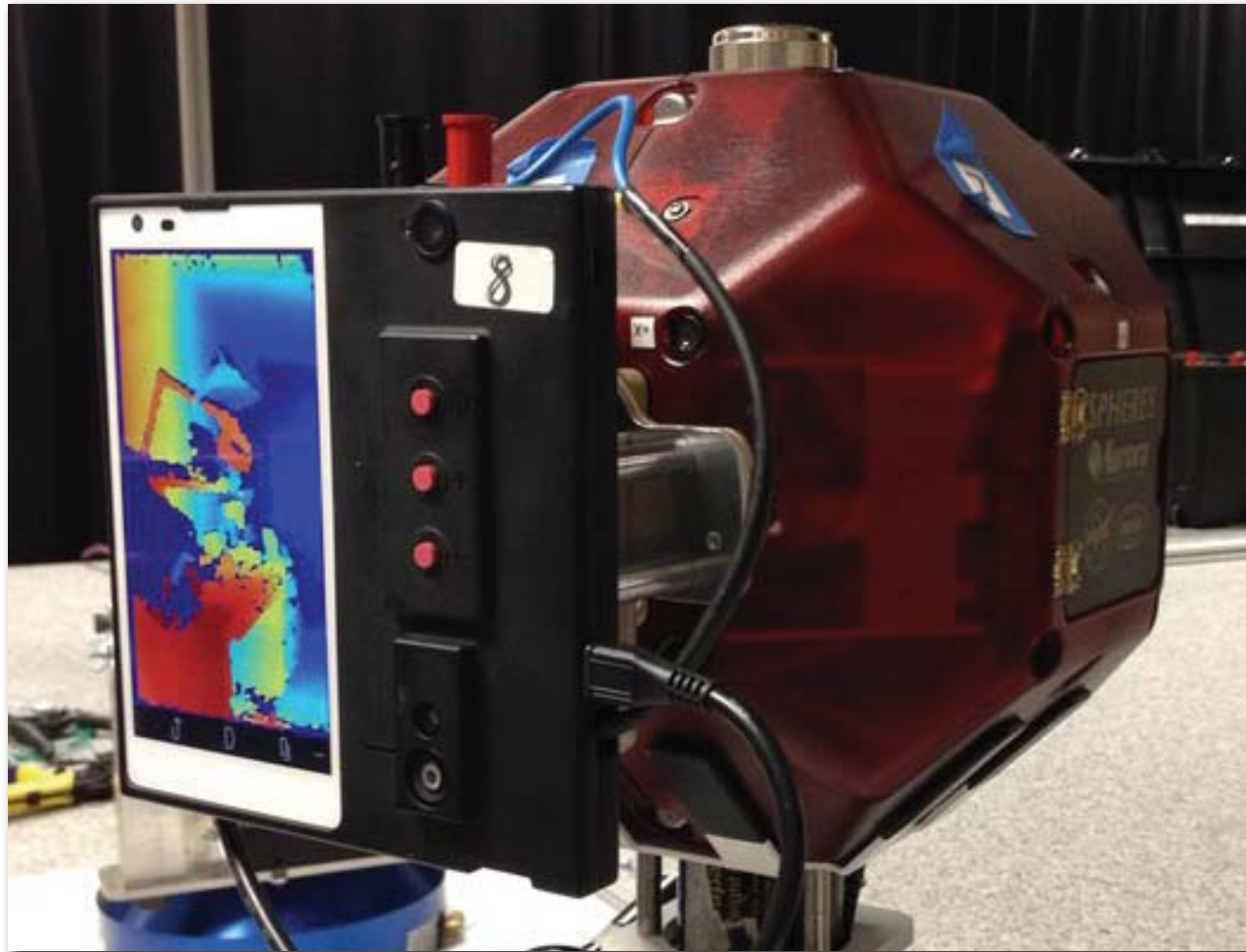


Image-based 3D reconstruction

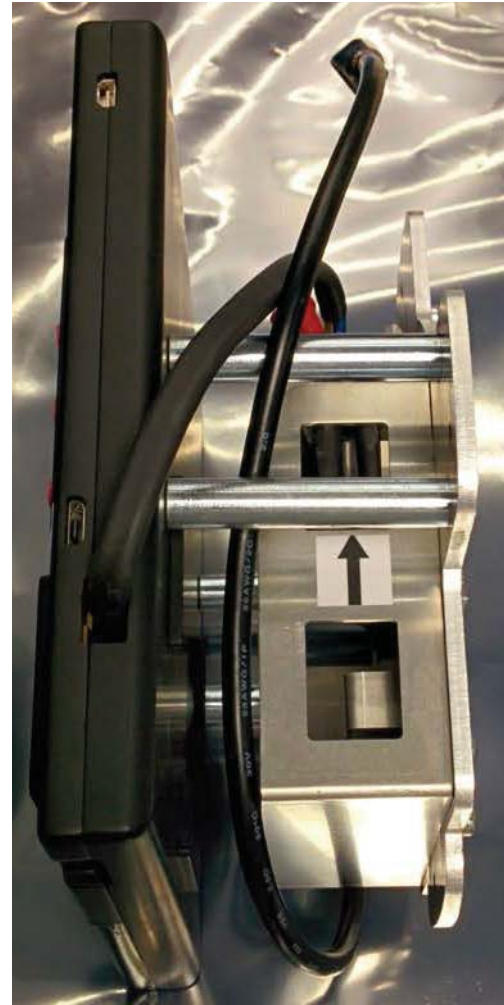
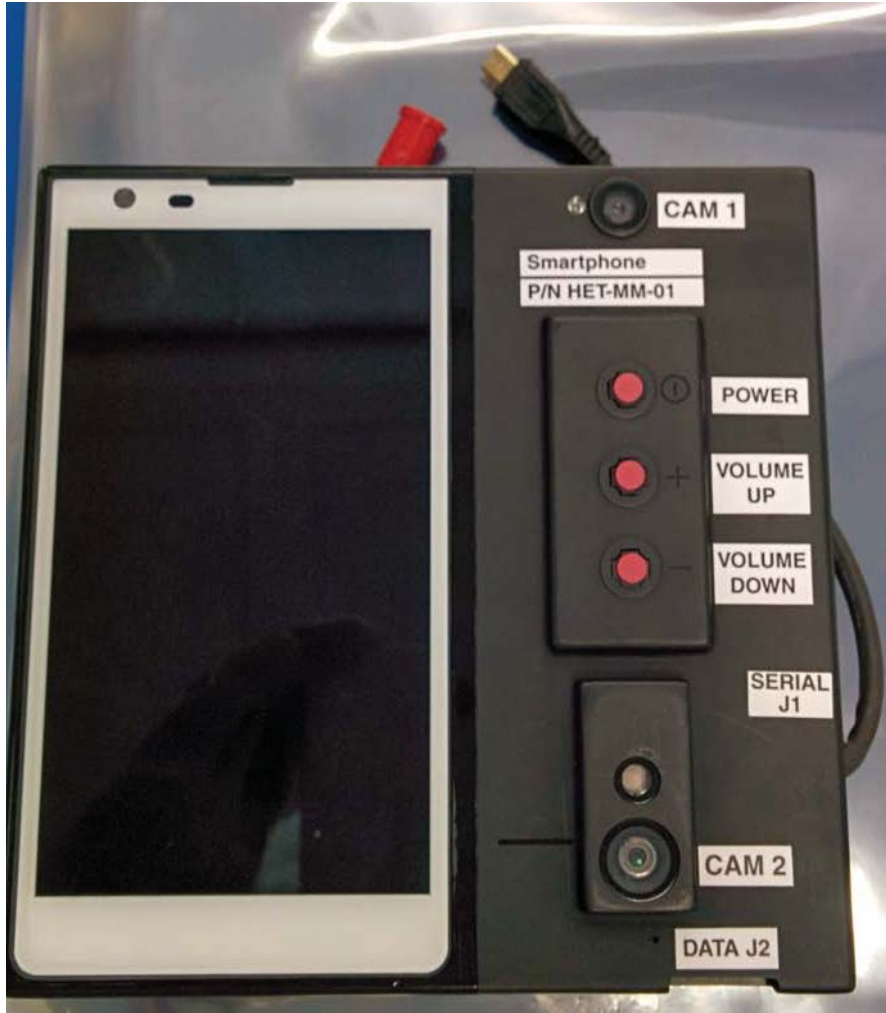
- Reconstructed using only camera images
- Shows position of camera for each image taken
- Shows inspection coverage



Modified Google “Project Tango” prototype smartphone
(scheduled for delivery to ISS on Orbital-2)



Smartphone flight unit





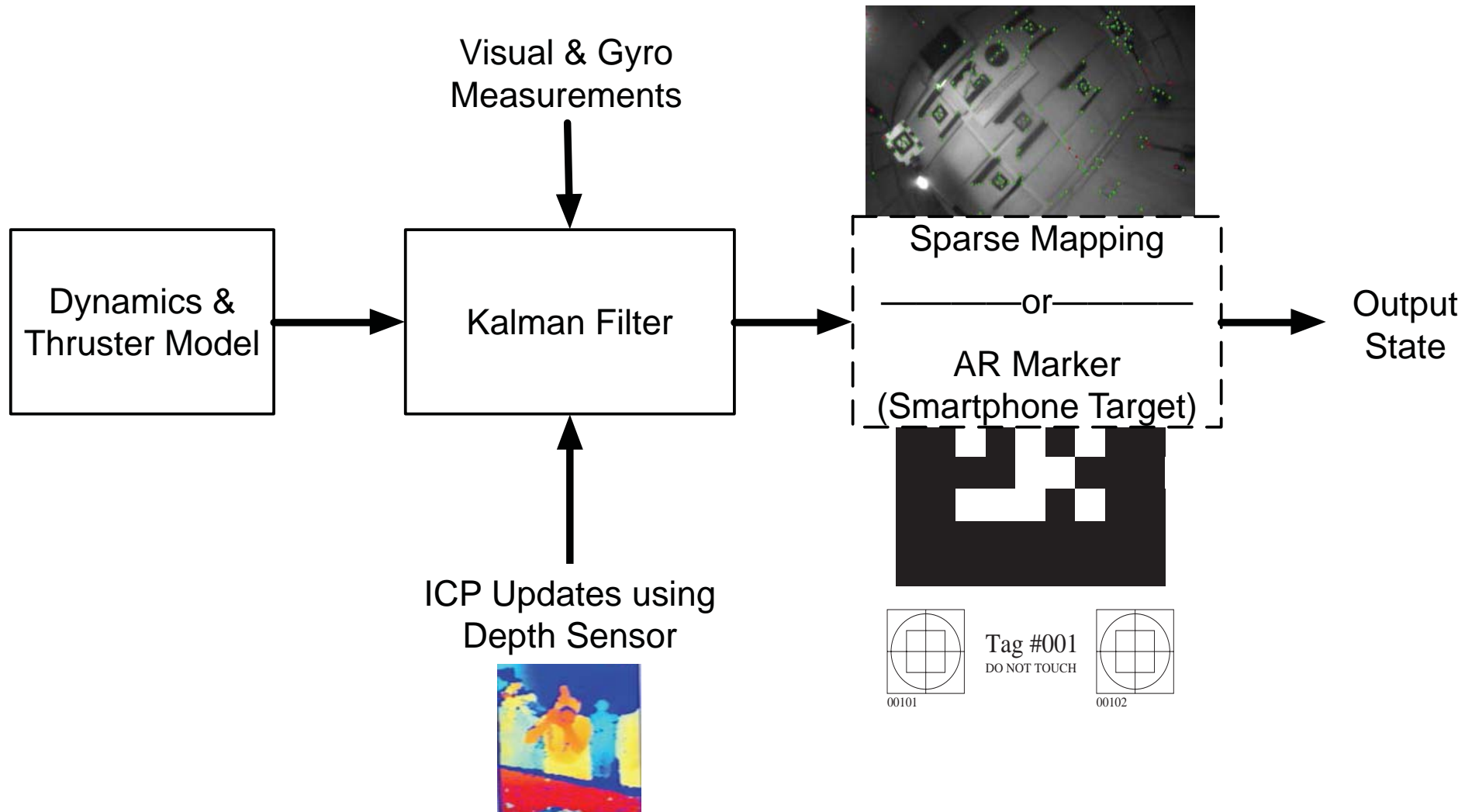
Smartphone parabolic flight test

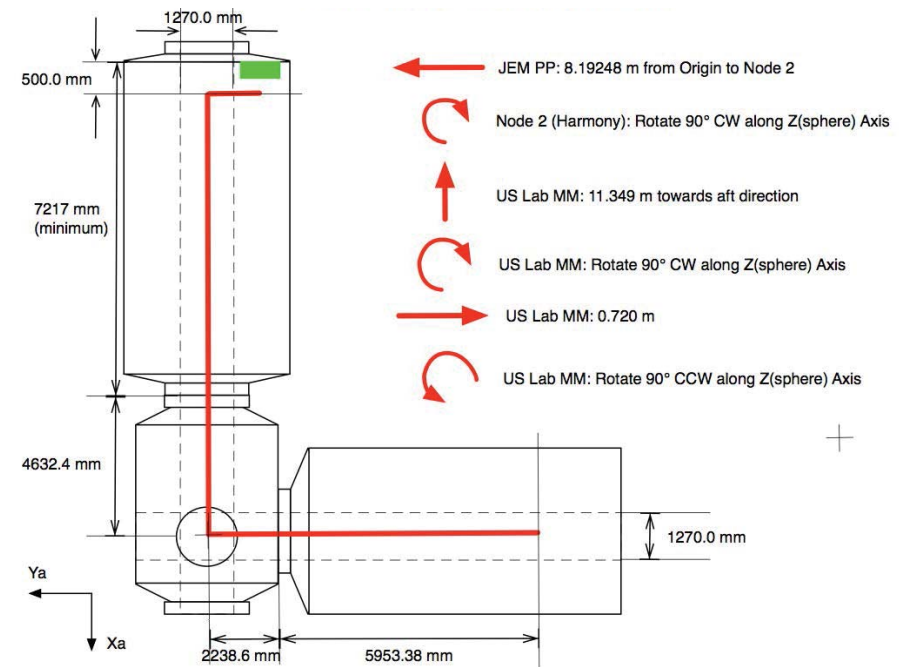


NASA – MIT SSL – UMD SPPL – DARPA – NRL – AFS – FIT



Smartphone-MM Localization

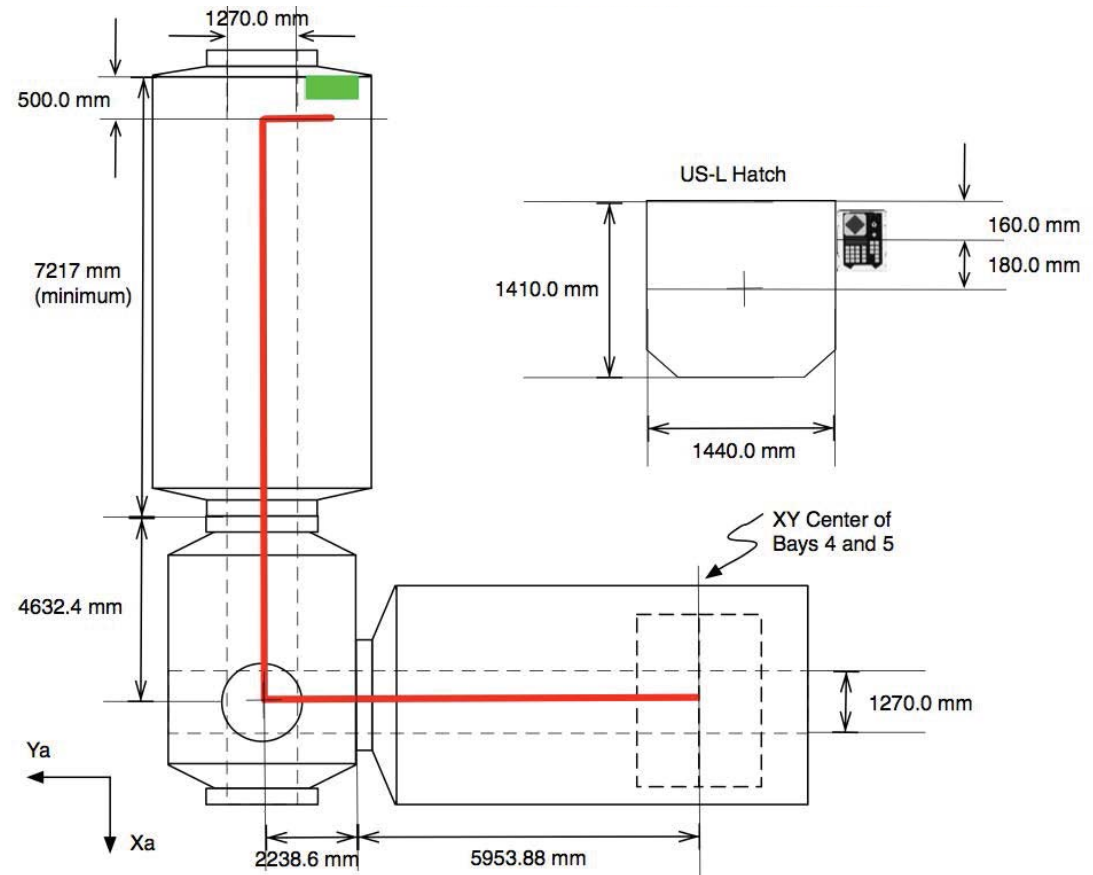






Smartphone ISS Nav Demo

- First run remains in SPHERES beacon volume
- Subsequent runs to Node 2 and US Lab
- Limited to 20 mins of actual runs (data downlink constraints)





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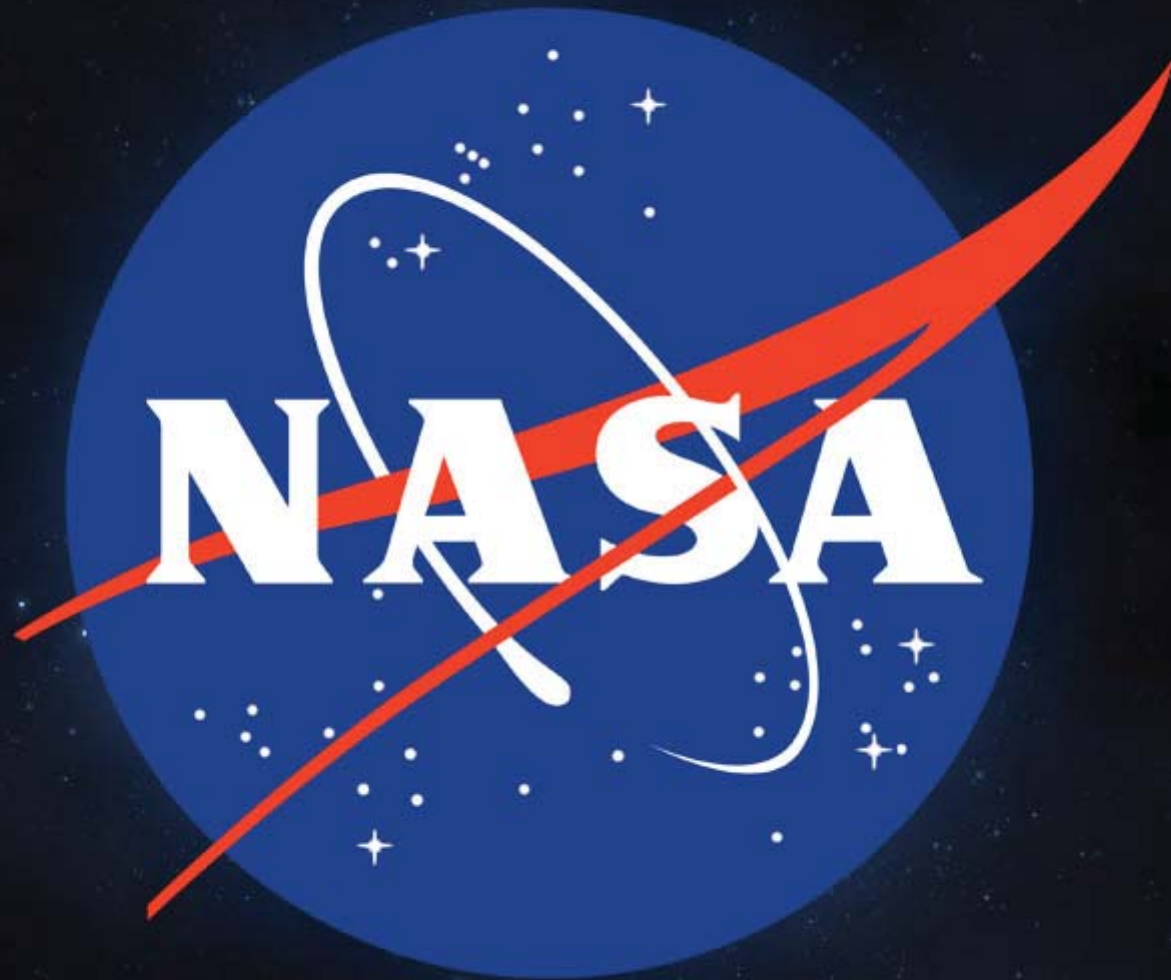
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Questions?





<http://www.nasa.gov/spheres>